

**Lake and Wetland Monitoring Program**

**2001 Annual Report**

**By**

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**Bureau of Environmental Field Services  
Division of Environment  
Kansas Department of Health & Environment**

after being 10 years of age.

1895, 1896, 1897

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1901, 1902, 1903

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## Executive Summary

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program surveyed the water quality conditions of 35 Kansas lakes during 2001. Nine of the lakes surveyed were large federal impoundments, 14 were State Fishing Lakes (SFLs), and 11 were city and county lakes. The remaining lake, Murray Gill Lake, is owned by the Boy Scouts of America and was surveyed as an ecoregional reference site. At the request of KDHE, Lake Meade was surveyed several times during the summer, by staff of the Kansas Department of Wildlife and Parks (KDWP). Information derived from this work was applied by KDHE in the development of Total Maximum Daily Loads (TMDLs) for pollutants entering the lake.

Of the 35 lakes surveyed, 54% indicated trophic state conditions comparable to their historic mean water quality conditions. Another 9% indicated improved water quality conditions, over mean historic condition, as evidenced by a lowered lake trophic state. The remaining 37% indicated degraded water quality, over historic mean condition, as evidenced by elevated lake trophic state conditions. One lake (Sedan South Lake) was new to the network but did have past data, from a statewide synoptic survey, with which to compare. Phosphorus was identified as the primary limiting factor in 34% of the lakes surveyed during 2001. Nitrogen was identified as the primary limiting factor in 29% of the lakes, while another 9% were identified as primarily light limited. The remaining 28% were either co-limited by combinations of nutrients (20%), nutrients and light availability (6%), or competition with the macrophyte community (<3%).

There were a total of 187 documented exceedences of Kansas numeric and narrative water quality criteria, or Environmental Protection Agency (EPA) water quality guidelines, in the lakes surveyed during 2001. Of these 187 exceedences, 43% pertained to the aquatic life use and 57% concerned consumptive and recreational uses. Nearly 75% involved uses previously designated in the Kansas Surface Water Register. Approximately 25% were for uses that had not been formally designated or verified by use attainability analyses.

Twenty lakes (59% of those surveyed for pesticides) had detectable levels of at least one pesticide in their main bodies during 2001. Atrazine was detected in 19 of these waterbodies, once again making it the most commonly documented pesticide in Kansas lakes. One of the lakes surveyed in 2001 exceeded both the chronic aquatic life support criterion and the drinking water supply criterion for atrazine. A total of four different pesticides, and two pesticide degradation byproducts, were found in lakes during 2001.

## Introduction

The following report is a summary of the work done during the last year in the Department of Mathematics at the University of Cambridge. It is divided into two parts. The first part is a general survey of the work done in the Department, and the second part is a more detailed account of the work done in the Department of Pure Mathematics.

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## **INTRODUCTION**

### **Development of the Lake and Wetland Monitoring Program**

The Kansas Department of Health and Environment (KDHE) Lake and Wetland Monitoring Program was established in 1975 to fulfill the requirements of the 1972 Clean Water Act (Public Law 92-500) by providing Kansas with background water quality data for water supply and recreational impoundments, determining regional and time trends for those impoundments, and identifying pollution control and/or assessment needs within individual lake watersheds.

Program activities originally centered around a small sampling network comprised mostly of federal lakes, with sampling stations at numerous locations within each lake. In 1985, based on the results of statistical analyses conducted by KDHE, the number of stations per lake was reduced to a single station within the main body of each impoundment. This, and the elimination of parameters with limited interpretive value, allowed expansion of the lake network to its present 120 sites scattered throughout all the major drainage basins and physiographic regions of Kansas. The network remains dynamic, with lakes occasionally being dropped from active monitoring and/or replaced with more appropriate sites throughout the state.

In 1989, KDHE initiated a Taste and Odor/Algae Bloom Technical Assistance Program for public drinking water supply lakes. This was done to assist water suppliers in the identification and control of taste and odor problems in finished drinking water that result from pollution, algae blooms, and natural ecological processes.

### **Overview of the 2001 Monitoring Activities**

Staff of the KDHE Lake and Wetland Monitoring Program visited 35 Kansas lakes during 2001. Nine of these lakes are large federal impoundments last sampled in 1998 or as part of special projects, 14 are State Fishing Lakes (SFLs), 11 are city/county lakes (CLs and Co. lakes, respectively), and one is owned and operated by the Boy Scouts of America. Fifteen of the 35 lakes (43%) serve as either primary or back-up municipal and/or industrial water supplies. Lake Meade was the site of 4 limited surveys during 2001. These surveys were conducted by the Kansas Department of Wildlife and Parks (KDWP) in support of KDHE Total Maximum Daily Load (TMDL) development efforts for that lake and watershed.

General information on the lakes surveyed during 2001 is compiled in Table 1. Figure 1 depicts the locations of the 35 lakes surveyed during 2001. Figure 2 depicts the locations of all currently active sites within the Lake and Wetland Monitoring Program. Additionally, a total of 11 lakes, streams, and ponds were investigated as part of the Taste and Odor/Algae Bloom Technical Assistance Program.

Created lakes are usually termed "reservoirs" or "impoundments," depending on whether they are used for drinking water supply or for other beneficial uses, respectively. In many parts of the

country, smaller lakes are termed "ponds" based on arbitrary surface area criteria. To provide consistency, this report uses the term "lake" to describe all non-wetland bodies of standing water within the state. The only exception to this is when more than one lake goes under the same general name. For example, the City of Herington has jurisdiction over two larger lakes. The older lake is referred to as Herington City Lake while the newer one is called Herington Reservoir in order to distinguish it from its sister waterbody.

## **METHODS**

### **Yearly Selection of Monitored Sites**

Since 1985, the 24 large federal lakes in Kansas have been arbitrarily partitioned into three groups of eight. Each group is normally sampled only once during a three year period of rotation. Up to 30 smaller lakes are sampled each year in addition to that year's block of eight federal lakes. These smaller lakes are chosen based on three considerations: 1) Are there recent data available (within the last 3-4 years) from KDHE or other programs?; 2) Is the lake showing indications of pollution that require enhanced monitoring?; or 3) Have there been water quality assessment requests from other administrative or regulatory agencies (state, local, or federal)? Several lakes have been added to the network due to their relatively unimpacted watersheds. These lakes serve as ecoregional reference sites.

### **Sampling Procedures**

At each lake, a boat is anchored over the inundated stream channel near the dam. This point is referred to as Station 1, and represents the area of maximum depth. Duplicate water samples are taken by Kemmerer sample bottle at 0.5 meters below the surface for determination of basic inorganic chemistry (major cations and anions), algal community composition, chlorophyll-a, nutrients (ammonia, nitrate, nitrite, Kjeldahl nitrogen, total organic carbon, and total and ortho phosphorus), and total recoverable metals/metalloids (aluminum, antimony, arsenic, barium, beryllium, cadmium, chromium, cobalt, copper, iron, lead, manganese, mercury, molybdenum, nickel, selenium, silver, thallium, vanadium, and zinc). Duplicate water samples are also taken at 0.5 to 1.0 meters above the lake substrate for determination of inorganic chemistry, nutrients, and metals/metalloids within the hypolimnion. In addition, a single pesticide sample, and duplicate fecal coliform bacteria samples, are collected at 0.5 meters depth at the primary sampling point (KDHE, 2000).

At each lake, measurements are made at Station 1 for temperature and dissolved oxygen profiles, field pH, photosynthetically active radiation (PAR) extinction, and Secchi disk depth. All samples are preserved and stored in the field in accordance with KDHE Quality Assurance/Quality Control protocols (KDHE, 2000). Field measurements, chlorophyll-a analyses, and algal taxonomic determinations are conducted by staff of KDHE's Bureau of Environmental Field Services. All other analyses are carried out by the KDHE Health and Environmental Laboratory (KHEL) (KDHE, 1995).

Table 1. General information pertaining to lakes surveyed during 2001. NGO refers to a "non-governmental organization."

Lake	Basin	Authority	Water Supply	Last Survey
Atchison Co. SFL	Kansas/Lower Republican	State	no	1998
Big Hill Lake	Verdigris	Federal	yes	1998
Bourbon Co. SFL	Marais des Cygnes	State	no	1997
Brown Co. SFL	Missouri	State	no	1997
Cowley Co. SFL	Lower Arkansas	State	no	1997
Elk City Lake	Verdigris	Federal	yes	1998
Eureka City Lake	Verdigris	City	yes	1997
Fall River Lake	Verdigris	Federal	yes	1998
Gridley City Lake	Neosho	City	no	1997
Hillsdale Lake	Marais des Cygnes	Federal	yes	2000
Kingman Co. SFL	Lower Arkansas	State	no	1997
Kirwin Lake	Solomon	Federal	no	1998
Lake Meade SFL	Cimarron	State	no	1999
Leavenworth Co. SFL	Kansas/Lower Republican	State	no	1997
Lovewell Lake	Kansas/Lower Republican	Federal	no	1998
Marion Co. Lake	Neosho	County	no	1997
McPherson Co. SFL	Smoky Hill/Saline	State	no	1997
Montgomery Co. SFL	Verdigris	State	no	1997
Mound City Lake	Marais des Cygnes	City	yes	1997
Murray Gill Lake	Verdigris	NGO	yes	2000
Neosho Co. SFL	Neosho	State	no	1997
Norton Lake	Upper Republican	Federal	yes	1998
Osage Co. SFL	Marais des Cygnes	State	no	1997
Pottawatomie Co. SFL #1	Kansas/Lower Republican	State	no	1998
Pottawatomie Co. SFL #2	Kansas/Lower Republican	State	no	1998
Sedan South Lake	Verdigris	City	yes	new to network
Shawnee Mission Lake	Kansas/Lower Republican	City	no	1996

Lake	Basin	Authority	Water Supply	Last Survey
Strowbridge Reservoir	Kansas/Lower Republican	City	yes	1997
Toronto Lake	Verdigris	Federal	yes	1998
Wabaunsee Co. Lake	Kansas/Lower Republican	County	yes	1997
Waconda Lake	Solomon	Federal	yes	1998
Wellington City Lake	Lower Arkansas	City	yes	1997
Winfield City Lake	Walnut	City	yes	1997
Woodson Co. SFL	Verdigris	State	no	1997
Wyandotte Co. Lake	Missouri	County	no	1997

Since 1992, macrophyte surveys have been conducted at each of the smaller lakes (<300 acres) within the KDHE Lake and Wetland Monitoring Program network. These surveys entail the selection and mapping of 10 to 20 sampling points, depending on total surface area and lake morphometry, distributed on a field map in a regular pattern over the lake surface. At each sampling point, a grappling hook is cast to rake the bottom for submersed aquatic plants. This process, combined with visual observations at each station, confirms the presence or absence of macrophytes at each station. If present, macrophyte species are identified and recorded on site. Specimens that cannot be identified in the field are placed in labeled plastic bags, on ice, for identification at the KDHE Topeka office. Presence/absence data, and taxon specific presence/absence data, are used to calculate a spacial coverage (percent distribution) estimate for each lake (KDHE, 2000).

#### Taste and Odor/Algae Bloom Program

In 1989, KDHE initiated a formal Taste and Odor/Algae Bloom Technical Assistance Program. Technical assistance concerning taste and odor incidences in water supply lakes, or algae blooms in lakes and ponds, may take on varied forms. Investigations may simply involve identification of algal species present within a lake, or they may entail the measurement of numerous physical, chemical, or biological parameters including watershed land use analysis to identify nonpoint pollution sources. Investigations are generally initiated at the request of water treatment plant personnel, or personnel at the KDHE district offices. While lakes used for public water supply are the primary focus, a wide variety of samples related to algae, odors, and fishkills, from both lakes and streams, are accepted for analysis.

Figure 1. Locations of the 35 lakes surveyed during 2001.

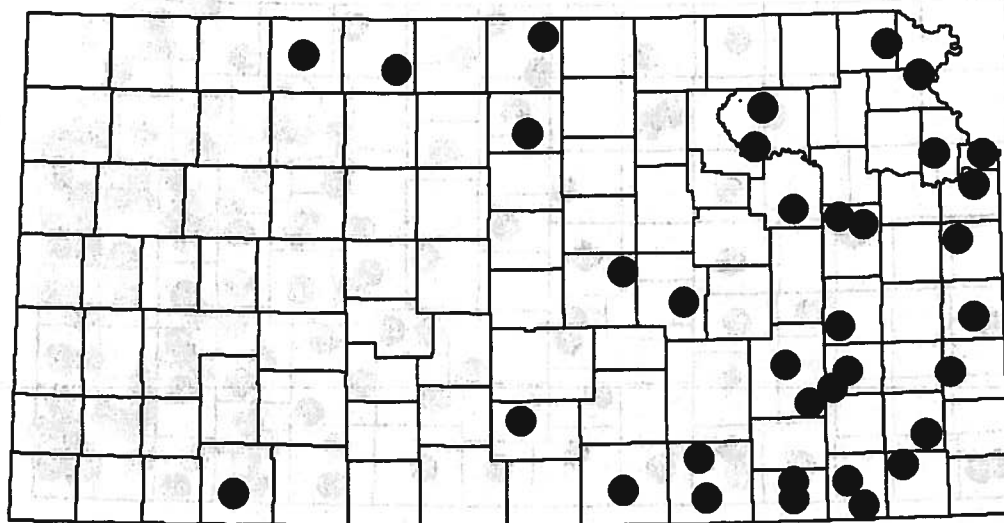
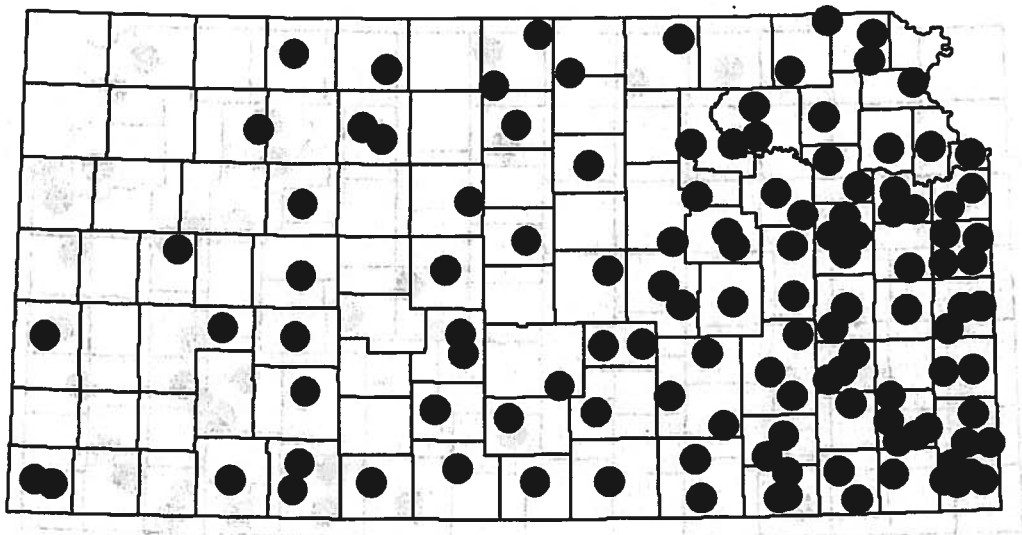


Figure 2. Locations of all currently active lake and wetland sampling sites within the KDHE Lake and Wetland Monitoring Program.



## RESULTS AND DISCUSSION

### Lake Trophic State

The Carlson Chlorophyll-a Trophic State Index (TSI) provides a useful tool for the comparison of lakes in regard to general ecological functioning and level of productivity (Carlson, 1977). Table 2 presents TSI scores for the 35 lakes surveyed during 2001, previous TSI mean scores for those lakes with past data, and an indication of the extent that lake productivity is dominated by submersed and floating-leaved vascular plant communities (macrophytes). Since chlorophyll-a TSI scores are based on the planktonic algae community, production due to macrophyte beds is not reflected in these scores. The system used to assign lake trophic state, based on TSI scores, is presented below. Trophic state classification is adjusted for macrophytes where percent areal cover (as estimated by percent presence) is greater than 50%, and visual bed volume and plant density clearly indicate that macrophyte productivity contributes significantly to overall lake primary production.

TSI score of 0-39 = oligo-mesotrophic (OM)

OM = A lake with a low level of planktonic algae. Such lakes also lack significant amounts of suspended clay particles in the water column, giving them a relatively high level of water clarity. Chlorophyll-a concentration averages no more than 2.5 ug/L.

TSI score of 40-49 = mesotrophic (M)

M = A lake with only a moderate planktonic algal community. Water clarity remains relatively high. Chlorophyll-a ranges from 2.51 to 7.2 ug/L.

TSI score of 50-63 = eutrophic (E)

E = A lake with a moderate-to-large algae community. Chlorophyll-a ranges from 7.21 to 30.0 ug/L. This category is further divided as follows:

TSI = 50-54 = slightly eutrophic (SE)

Chlorophyll-a ranges 7.21 to 12.0 ug/L,

TSI = 55-59 = fully eutrophic (E)

Chlorophyll-a ranges 12.01 to 20.0 ug/L,

TSI = 60-63 = very eutrophic (VE)

Chlorophyll-a ranges 20.01 to 30.0 ug/L.

TSI score of  $\geq 64$  = hypereutrophic (H)

H = A lake with a very large phytoplankton community. Chlorophyll-a averages more than 30.0 ug/L. This category is further divided as follows:

TSI = 64-69.9 = lower hypereutrophic      Chlorophyll-a ranges 30.01 to 55.99 ug/L,

TSI =  $\geq 70$  = upper hypereutrophic      Chlorophyll-a ranges  $\geq 56$  ug/L.

TSI score not relevant = argillotrophic (A)

A = In a number of Kansas lakes, high turbidity due to suspended clay particles restricts the development of a phytoplankton community. In such cases, nutrient availability remains high, but is not fully translated into algal productivity or biomass due to light limitation. Lakes with such high turbidity and nutrient levels, but lower than expected algal biomass, are called argillotrophic (Naumann, 1929) rather than oligo-mesotrophic, mesotrophic, etc. These lakes may have chronic high turbidity, or may only experience sporadic (but frequent) episodes of dis-equilibria following storm events that create "over flows" of turbid runoff on the lake surface. Frequent wind resuspension of sediments, as well as benthic feeding fish communities (e.g., common carp), can create these conditions as well. Argillotrophic lakes also tend to have very small, or nonexistent, submersed macrophyte communities. Mean chlorophyll-a measures  $\leq 7.2$  ug/L as a general rule.

All Carlson chlorophyll TSI scores are calculated by the following formula, where C is the phaeophytin corrected chlorophyll-a level in ug/L (Carlson, 1977):

$$TSI = 10(6 - (2.04 - 0.68 \log_e(C)) / \log_e(2)).$$

The composition of the algal community (structural feature) often gives a better ecological picture of a lake than relying solely on a trophic state classification (functional feature). Table 3 presents both total algal cell count and percent composition of several major algal groups for the lakes surveyed in 2001. Lakes in Kansas that are nutrient enriched tend to be dominated by green or blue-green algae, while those dominated by diatom communities may not be so enriched. Certain species of green, blue-green, diatom, or dinoflagellate algae may contribute to taste and odor problems in finished drinking water, when present in large numbers in lakes and streams.

Table 4 presents biovolume data for the 35 lakes surveyed in 2001. When compared to cell counts, such data are useful in determining which species or algae groups actually exert the strongest ecological influence on a lake.

Table 2. Current and past TSI scores, and trophic state classification for the lakes surveyed during 2001. Trophic class abbreviations used previously apply. An asterisk appearing after the lake name indicates that the lake was dominated by macrophyte production. In such a case, the trophic class is adjusted, and the adjusted trophic state class given in parentheses. Previous TSI scores are based only on algal chlorophyll TSI score.

Lake	2001 TSI/Class	Previous Trophic Class Period of Record Mean
Atchison Co. SFL	62.4 VE	VE
Big Hill Lake	57.9 E	SE
Bourbon Co. SFL	69.6 H	E
Brown Co. SFL	72.9 H	H
Cowley Co. SFL	56.5 E	SE
Elk City Lake	61.0 VE	SE
Eureka City Lake	67.1 H	E
Fall River Lake	51.0 SE to A	SE
Gridley City Lake	61.9 VE	VE
Hillsdale Lake Station 1 (Main Body)	60.1 VE	SE
Hillsdale Lake Station 2 (Big Bull Creek Arm)	61.0 VE	E
Hillsdale Lake Station 3 (Little Bull Creek Arm)	60.7 VE	E
Hillsdale Lake (Whole Lake) <sup>s</sup>	60.6 VE	E
Kingman Co. SFL *	43.7 M (E)	M
Kirwin Lake	61.4 VE	VE
Lake Meade SFL	66.3 H	H
Leavenworth Co. SFL	61.6 VE	E
Lovewell Lake	68.1 H	VE
Marion Co. Lake	59.3 E	E
McPherson Co. SFL	78.5 H	H
Montgomery Co. SFL	73.4 H	H
Mound City Lake	61.5 VE	VE
Murray Gill Lake	44.5 M	M
Neosho Co. SFL	63.7 VE	H

Lake	2001 TSI/Class	Previous Trophic Class Period of Record Mean
Norton Lake	58.2 E	E
Osage Co. SFL	48.2 M	SE
Pottawatomie Co. SFL #1	64.9 H	E
Pottawatomie Co. SFL #2	44.5 M	M
Sedan South Lake	49.2 M	M
Shawnee Mission Lake	45.0 M	M
Strowbridge Reservoir	54.7 SE	SE
Toronto Lake	56.5 E	SE
Wabaunsee Co. Lake	56.0 E	M
Waconda Lake	51.7 SE	E
Wellington City Lake	50.0 A	A
Winfield City Lake	59.2 E	E
Woodson Co. SFL	52.0 SE	M
Wyandotte Co. Lake	55.1 E	SE

<sup>s</sup> = Hillsdale Lake represents a special case as the whole lake TSI is the mean of three individual stations within the lake.

### Trends in Trophic State

Table 5 summarizes changes in trophic status for the 35 lakes surveyed during 2001. Thirteen lakes (37%) displayed increases in trophic state, over their historic mean condition, while three lakes (9%) displayed improved trophic states. Stable conditions were noted in 19 lakes (54%). This is a larger percentage of lakes showing increased trophic state, compared to historic condition, than last year. It is very possible that the extended period of heat and dry weather in the summer of 2001 contributed to this.

As shown in Table 6, of the 20 lakes receiving macrophyte surveys 12 (60%) had detectable amounts of plant material. In these lakes, the most common plant species were pondweeds (Potamogeton spp.), water naiad (Najas guadalupensis), coontail (Ceratophyllum demersum), parrot feather (Myriophyllum spp.), and various species of stonewort algae (Chara spp.). Macrophyte species detected in 2001 were similar to previous years, although Myriophyllum spp., frequently noted as nuisance organisms in the literature, are becoming more frequently encountered around the state.

Table 3. Algal communities observed in the 35 lakes surveyed during 2001. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate forms of algae.

Lake	Cell Count (cells/mL)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Atchison Co. SFL	79,475	2	96	1	1
Big Hill Lake	59,346	<1	99	<1	<1
Bourbon Co. SFL	101,682	4	95	1	<1
Brown Co. SFL	300,825	0	100	0	0
Cowley Co. SFL	12,254	<3	87	11	<2
Elk City Lake	24,633	11	79	9	1
Eureka City Lake	4,662	27	9	22	42
Fall River Lake	2,930	41	34	25	0
Gridley City Lake	6,741	62	0	9	29
Hillsdale Lake Station 1	111,132	0	96	4	0
Hillsdale Lake Station 2	39,407	1	85	13	1
Hillsdale Lake Station 3	48,636	3	89	7	1
Hillsdale Lake (mean)	66,392	1	90	8	1
Kingman Co. SFL	1,134	65	23	0	12
Kirwin Lake	34,367	14	83	3	<1
Lake Meade SFL	753,291	3	94	3	0
Leavenworth Co. SFL	5,891	24	42	22	12
Lovewell Lake	93,177	5	93	1	<1
Marion Co. Lake	17,357	5	70	22	3
McPherson Co. SFL	159,327	1	99	0	0
Montgomery Co. SFL	137,025	<1	99	<1	<1
Mound City Lake	7,938	42	10	46	2
Murray Gill Lake	3,024	23	59	17	1
Neosho Co. SFL	16,947	10	76	10	4

Lake	Cell Count (cells/mL)	Percent Composition			
		Greens	Blue-Greens	Diatoms	Other
Norton Lake	4,851	53	25	16	6
Osage Co. SFL	1,670	28	60	4	8
Pottawatomie Co. SFL #1	28,854	13	77	8	2
Pottawatomie Co. SFL #2	2,300	44	31	5	20
Sedan South Lake	9,104	6	89	4	1
Shawnee Mission Lake	473	100	0	0	0
Strowbridge Reservoir	3,150	12	31	49	8
Toronto Lake	7,781	8	13	78	1
Wabaunsee Co. Lake	17,987	5	93	2	0
Waconda Lake	9,482	4	85	8	3
Wellington City Lake	1,197	36	0	40	24
Winfield City Lake	9,513	27	12	59	2
Woodson Co. SFL	13,293	11	80	2	7
Wyandotte Co. Lake	21,263	4	92	2	2

Table 4. Algal biovolumes calculated for the lakes surveyed during 2001. The "other" category refers to euglenoids, cryptophytes, dinoflagellates, and other single-celled flagellate forms of algae. Biovolume units are calculated in  $\text{mm}^3/\text{L}$ , and expressed as parts-per-million (ppm).

Lake	Biovolume (ppm)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Atchison Co. SFL	26.206	3	71	21	5
Big Hill Lake	19.703	1	94	3	<2
Bourbon Co. SFL	28.190	12	77	6	5
Brown Co. SFL	170.110	0	100	0	0
Cowley Co. SFL	16.147	3	38	59	0
Elk City Lake	14.639	12	3	81	4
Eureka City Lake	13.492	11	2	12	75
Fall River Lake	4.196	27	4	69	0
Gridley City Lake	10.582	25	0	18	57
Hillsdale Lake Sta. 1	27.722	<2	48	51	<1
Hillsdale Lake Sta. 2	30.350	1	12	65	22
Hillsdale Lake Sta. 3	21.570	6	25	49	20
Hillsdale Lake (mean)	26.547	3	28	55	14
Kingman Co. SFL	0.960	59	7	0	34
Kirwin Lake	9.812	27	51	12	10
Lake Meade SFL	69.656	35	47	17	<1
Leavenworth Co. SFL	9.453	8	1	63	28
Lovewell Lake	37.954	4	86	5	5
Marion Co. Lake	20.850	1	25	60	14
McPherson Co. SFL	310.314	1	99	0	0
Montgomery Co. SFL	101.519	<1	97	2	<1
Mound City Lake	11.247	22	1	64	13
Murray Gill Lake	1.277	18	44	31	7
Neosho Co. SFL	27.003	2	66	15	17

Lake	Biovolume (ppm)	Percent Composition			
		Green	Blue-Green	Diatom	Other
Norton Lake	6.934	46	7	14	33
Osage Co. SFL	2.707	18	11	12	59
Pottawatomie Co. SFL	33.764	4	66	25	5
Pottawatomie Co. SFL	2.412	20	16	7	57
Sedan South Lake	2.172	24	51	7	18
Shawnee Mission Lake	0.154	100	0	0	0
Strowbridge Reservoir	6.614	6	6	74	14
Toronto Lake	26.701	1	2	96	1
Wabaunsee Co. Lake	10.450	6	75	17	2
Waconda Lake	4.493	4	7	74	15
Wellington City Lake	2.394	4	0	68	28
Winfield City Lake	22.925	8	1	82	9
Woodson Co. SFL	4.071	8	38	5	49
Wyandotte Co. Lake	4.919	6	65	14	15

### Lake Stratification

Stratification is a natural process that may occur in any standing (lentic) body of water, whether that body is a natural lake, pond, artificial reservoir, or wetland pool (Wetzel, 1983). It occurs when sunlight (solar energy) penetrates into the water column. Due to the thermal properties of water, high levels of sunlight (combined with calm winds during the spring-to-summer months) cause layers of water to form with differing temperatures and densities. The cooler, denser layer (the hypolimnion) remains near the bottom of the lake while the upper layer (the epilimnion) develops a higher ambient temperature. The middle layer (the metalimnion) displays a marked drop in temperature with depth (the thermocline), compared to conditions within the epilimnion and hypolimnion.

**Table 5.** Trends over time, based on a comparison to mean historic condition, for lake trophic state classification within each major river basin in Kansas. Only those basins visited during 2001 are included.

<b>Basin</b>	<b>Number of Lakes</b>		
	<b>Stable</b>	<b>Improving</b>	<b>Degrading</b>
Cimarron	1	0	0
Kansas/Lower Republican	4	0	4
Lower Arkansas	2	0	1
Marais des Cygnes	1	1	2
Missouri	1	0	1
Neosho	2	1	0
Smoky Hill/Saline	1	0	0
Solomon	1	1	0
Upper Republican	1	0	0
Verdigris	4	0	5
Walnut	1	0	0
<b>Total</b>	<b>19</b>	<b>3</b>	<b>13</b>

Once these layers of water with differing temperatures form, they tend to remain stable and do not easily mix with one another. This formation of distinct layers impedes, or precludes, the atmospheric reaeration of the hypolimnion, at least for the duration of the summer (or until ambient conditions force mixing). In many cases, this causes hypolimnetic waters to become depleted of oxygen and unavailable as habitat for fish and other forms of aquatic life. Stratification eventually breaks down in the fall when surface waters cool. Once epilimnetic waters cool to temperatures comparable to hypolimnetic waters, the lake will mix completely once again. Typically occurring in the fall, this phenomenon is called "lake turnover."

Lake turnover can cause fishkills, aesthetic problems, and taste and odor problems in finished drinking water if the hypolimnion comprises a significant volume of the lake. This is because such a sudden mixing combines oxygen-poor, nutrient-rich hypolimnetic water with epilimnetic water lower in nutrients and richer in dissolved oxygen. Lake turnover can result in explosive algal growth, lowering of overall lake oxygen levels, and sudden fishkills. It also often imparts objectionable odors to the lake water and tastes and odors to finished drinking water produced from the lake. Thus, the stratification process is an important consideration in lake management.

Table 6. Macrophyte community structure in the 20 lakes surveyed for macrophytes during 2001. Macrophyte community refers only to the submersed and floating-leaved aquatic plants, not emergent shoreline plants. The percent areal cover is the abundance estimate for each documented species (Note: due to overlap in cover, the percentages under community composition may not equal the total cover).

Lake	% Total Cover	% Species Cover and Community Composition
Atchison Co. SFL	80%	80% <i>Najas guadalupensis</i> 67% <i>Potamogeton nodosus</i> 53% <i>Ceratophyllum demersum</i>
Bourbon Co. SFL	7%	7% <i>Chara zeylanica</i> 7% <i>Fontinalis</i> sp.
Brown Co. SFL	70%	70% <i>Ceratophyllum demersum</i> 60% <i>Najas guadalupensis</i> 60% <i>Potamogeton pectinatus</i> 50% <i>Potamogeton nodosus</i>
Cowley Co. SFL	20%	15% <i>Myriophyllum</i> sp. 15% <i>Najas guadalupensis</i> 10% <i>Chara globularis</i> 10% <i>Nymphaea</i> sp.
Eureka City Lake	<5%	no species observed
Gridley City Lake	50%	40% <i>Myriophyllum</i> sp. 20% <i>Potamogeton nodosus</i> 20% <i>Potamogeton pectinatus</i> 10% <i>Najas guadalupensis</i>
Kingman Co. SFL	100%	100% <i>Ceratophyllum demersum</i> 100% <i>Najas guadalupensis</i> 100% <i>Potamogeton crispus</i> 100% <i>Potamogeton nodosus</i> 100% <i>Potamogeton pectinatus</i> 20% <i>Nelumbo</i> sp. 15% <i>Potamogeton zosteriformis</i>
Leavenworth Co. SFL	40%	25% <i>Ceratophyllum demersum</i> 25% <i>Najas guadalupensis</i> 20% <i>Potamogeton crispus</i> 15% <i>Chara zeylanica</i>
Marion Co. Lake	<5%	no species observed
McPherson Co. SFL	73%	60% <i>Najas guadalupensis</i> 33% <i>Potamogeton gramineus</i> 13% <i>Ceratophyllum demersum</i>
Montgomery Co. SFL	<7%	trace <i>Najas guadalupensis</i>

Lake	% Total Cover	% Species Cover and Community Composition
Mound City Lake	70%	60% <i>Najas guadalupensis</i> 60% <i>Potamogeton nodosus</i> 35% <i>Chara vulgaris</i> 30% <i>Chara globularis</i> 20% <i>Potamogeton pectinatus</i> 5% <i>Ceratophyllum demersum</i> 5% <i>Nelumbo sp.</i>
Neosho Co. SFL	<7%	no species observed
Osage Co. SFL	<5%	trace <i>Najas guadalupensis</i>
Pottawatomie Co. SFL #1	67%	67% <i>Ceratophyllum demersum</i> 53% <i>Najas guadalupensis</i>
Pottawatomie Co. SFL #2	65%	41% <i>Chara globularis</i> 41% <i>Potamogeton nodosus</i> 35% <i>Najas guadalupensis</i> 24% <i>Ceratophyllum demersum</i> 6% <i>Potamogeton illinoensis</i> 6% <i>Potamogeton pectinatus</i>
Sedan South Lake	<7%	trace <i>Najas guadalupensis</i>
Strowbridge Reservoir	<5%	no species observed
Wabaunsee Co. Lake	<5%	no species observed
Woodson Co. SFL	30%	25% <i>Chara zeylanica</i> 10% <i>Nelumbo sp.</i> 5% <i>Najas guadalupensis</i>

The "enrichment" of hypolimnetic waters (with nutrients, metals, and other pollutants) during stratification results from the entrapment of materials that sink down from above, as well as materials that are released from lake sediments due to anoxic conditions. The proportion of each depends on the strength and duration of stratification, existing sediment quality, and inflow of materials from the watershed.

Sediment re-release of materials, and water quality impact at turnover, would be most pronounced in a deep, moderate-to-small sized lake, with abundant protection from the wind, shallow thermocline, and a history of high pollutant loads from the watershed. For the majority of our larger lakes in Kansas, built on major rivers with dependable flow, stratification tends to be intermittent (polymictic), or missing, and the volume of the hypolimnion tends to be small in proportion to total lake volume. These conditions tend to lessen the importance of sediment re-release of pollutants in the largest Kansas lakes, leaving watershed pollutant inputs as the primary cause of water quality problems.

Table 7. Lake stratification status for the 35 lakes surveyed during 2001. The term "n.a." indicates that boat access, wind conditions, shallowness, or equipment problems prevented taking profile data or made its acquisition superfluous.

Lake	Date Sampled	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)
Atchison Co. SFL	07-09-2001	2.67	1.25	1-3	6.0
Big Hill Lake	07-31-2001	0.92	0.52	5-8	13.0
Bourbon Co. SFL	08-13-2001	0.89	1.41	4-5	9.5
Brown Co. SFL	07-02-2001	1.56	2.27	2-4	4.5
Cowley Co. SFL	06-25-2001	0.88	1.00	5-7	8.5
Elk City Lake	07-23-2001	0.31	1.01	none	10.0
Eureka City Lake	06-25-2001	0.59	1.02	3-4	8.5
Fall River Lake	07-23-2001	0.50	0.91	none	7.0
Gridley City Lake	07-10-2001	0.57	1.74	2-3.5	3.5
Hillsdale Lake Station 1 (Main Body)	07-18-2001	0.54	0.59	8-9	13.0
Hillsdale Lake Station 2 (Big Bull Creek Arm)	07-18-2001	0.61	0.80	7-8	9.0
Hillsdale Lake Station 3 (Little Bull Creek Arm)	07-18-2001	0.69	1.01	6-8	8.0
Kingman Co. SFL	06-26-2001	1.50	0.35	none	2.0
Kirwin Lake	08-07-2001	0.46	0.63	9-11	12.5
Lake Meade	05-15-2001 to 08-20-2001	n.a.	n.a.	n.a.	3.0

Lake	Date Sampled	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)
Leavenworth Co. SFL	07-09-2001	0.20	0.56	none	10.0
Lovewell Lake	08-06-2001	0.25	1.03	5-6	8.5
Marion Co. Lake	07-16-2001	0.84	0.54	6-8	9.5
McPherson Co. SFL	07-16-2001	0.69	1.51	5-6	6.5
Montgomery Co. SFL	07-30-2001	2.15	1.65	3-5	7.0
Mound City Lake	06-21-2001	0.09	1.02	none	5.5
Murray Gill Lake	07-30-2001	1.33	0.54	4-7	13.5
Neosho Co. SFL	06-18-2001	1.23	1.14	2-4	6.5
Norton Lake	08-07-2001	0.15	0.69	none	11.0
Osage Co. SFL	08-22-2001	1.09	0.57	6-8	12.0
Pottawatomie Co. SFL #1	07-11-2001	1.10	1.34	2-4	5.0
Pottawatomie Co. SFL #2	07-11-2001	1.70	0.73	3-5	10.0
Sedan South Lake	07-30-2001	1.67	1.13	4-5	7.0
Shawnee Mission Lake	07-03-2001	1.60	0.73	2-4	10.0
Strowbridge Reservoir	08-22-2001	0.00	0.04	none	8.5
Toronto Lake	07-23-2001	0.60	1.10	3-4	5.0
Wabunsee Co. Lake	07-17-2001	0.82	0.61	5-7	11.0
Waconda Lake	08-07-2001	0.23	0.60	none	18.0

Lake	Date Sampled	Temperature Decline Rate (degree C/meter)	Dissolved Oxygen Decline Rate (mg/L/meter)	Thermocline Depth (meters)	Maximum Lake Depth (meters)
Wellington City Lake	06-26-2001	0.22	0.98	none	4.5
Winfield City Lake	06-26-2001	0.40	0.63	8-11	12.5
Woodson Co. SFL	06-18-2001	0.87	0.47	4-8	15.0
Wyandotte Co. Lake	07-25-2001	1.27	0.55	4-6	15.0

Presence or absence of stratification is determined by the depth profiles taken in each lake for temperature and dissolved oxygen concentration. Table 7 presents this data. Temperature decline rates (for the entire water column) greater than 1.0°C/m are considered evidence of stronger thermal stratification, although temperature changes may be less pronounced during the initiation phase of stratification. Lakes with strong thermal stratification will be more resistant to mixing of the entire water column pending the cooling of epilimnetic waters that accompanies fall.

The temperature decline rate, however, must also be considered in relation to the particular lake and the shape of the temperature-to-depth relationship. The sharper the discontinuity in the data plot, the stronger the level of thermal stratification. Gradual declines in temperature with depth, through the entire water column, and indistinct discontinuities in data plots are more indicative of weaker thermal stratification. The strength of the oxycline, based on water column decline rate and the shape of the data plot, is also used to estimate stratification in lakes. A strong oxycline might be seen by mid-summer in lakes with weak thermal stratification if the lakes are not prone to wind mixing, or in the case of dense macrophyte beds.

### Fecal Coliform Bacteria

Since 1996, bacterial sampling has taken place at the primary water quality sampling station at each lake. While many Kansas lakes have swimming beaches, many do not. However, presence or absence of a swimming beach does not determine whether or not a lake supports primary contact recreational use. Primary contact recreation is defined as, "recreation during which the body is immersed in surface water to the extent that some inadvertent ingestion of water is probable" (KDHE, 1999), which includes swimming, water skiing, wind surfing, jet skiing, diving, boating, and other similar activities. The majority of Kansas lakes have some form of primary contact recreation taking place during the warmer half of the year. Sampling of swimming beaches is also often conducted by lake managers to document water quality where people are concentrated in a small area. These managers are in the best position to collect samples frequently enough to determine compliance with the regulations (KDHE, 1999).

Given the rapid die-off of fecal coliform bacteria in the aquatic environment, due to protozoan predation and a generally hostile set of environmental conditions, high fecal coliform bacterial counts should only occur in the open water of a lake if there has been 1) a recent pollution event, or 2) a chronic input of bacteria-laced pollution. A single set of bacterial samples collected from the open, deep water, environment is normally considered representative of whole-lake bacterial water quality at the time of the survey. This environment is also less prone to short lived fluctuations in bacterial counts, than are swimming beaches or other shoreline type areas.

Table 8 presents the bacterial data collected during the 2001 sampling season. Five lakes, out of the 34 lakes surveyed for fecal coliform bacteria, had fecal coliform bacterial counts greater than the analytical reporting limit. However, no lake in 2001 exceeded existing criteria (KDHE, 1999).

Table 8. Fecal coliform bacterial counts (mean of duplicate samples) from the 34 lakes surveyed for fecal coliform bacteria during 2001. Note: These samples were collected during the week, not during weekends, when recreational activity would be at peak levels. All units are in "number of cfu/100 mL of lake water."

Lake	Site Location	Fecal Coliform Count
Atchison Co. SFL	open water	<10
Big Hill Lake	open water	<10
Bourbon Co. SFL	open water	<10
Brown Co. SFL	open water	<10
Cowley Co. SFL	open water	<10
Elk City Lake	open water	<10
Eureka City Lake	open water	<10
Fall River Lake	open water	<10
Gridley City Lake	open water	15
Hillsdale Lake	open water	<10
Kingman Co. SFL	open water	<10
Kirwin Lake	open water	<10
Leavenworth Co. SFL	open water	<10
Lovewell Lake	open water	<10
Marion Co. Lake	open water	<10
McPherson Co. SFL	open water	70
Montgomery Co. SFL	open water	<10
Mound City Lake	open water	<10
Murray Gill Lake	open water	<10
Neosho Co. SFL	open water	55
Norton Lake	open water	<10
Osage Co. SFL	open water	<10
Pottawatomie Co. SFL #1	open water	<15
Pottawatomie Co. SFL #2	open water	15
Sedan South Lake	open water	<10
Shawnee Mission Lake	open water	<10

Lake	Site Location	Fecal Coliform Count
Strowbridge Reservoir	open water	<10
Toronto Lake	open water	<10
Wabaunsee Co. Lake	open water	<10
Waconda Lake	open water	<10
Wellington City Lake	open water	15
Winfield City Lake	open water	<10
Woodson Co. SFL	open water	<20
Wyandotte Co. Lake	open water	<10

### Limiting Nutrients and Physical Parameters

The determination of which nutrient, or physical characteristic, “limits” phytoplankton production is of primary importance in lake management. If certain features can be identified, which exert exceptional influence on lake water quality, those features can be addressed in lake protection plans to a greater degree than less important factors. In this way, lake management can be made more efficient.

The concept of limiting nutrients, or limiting factors, is often difficult for the layman to grasp. The following analogy is provided in an attempt to clarify the concept.

A person is given 10 spoons, 9 knives, and 5 forks. They are then asked to place sets of utensils at each seat at a table. Further, only complete sets of utensils are to be placed, with a complete set consisting of all three utensils. The question is, “What utensil is the limiting factor in this situation?”

In this example, the number of available forks “limits” the number of place settings that can be made. So, “forks” is the “limiting factor” for this scenario.

In a lake ecosystem, the level of algal production is equivalent to the place setting, while plant nutrients, light availability, and other factors represent the spoons, knives, and forks. Common factors that limit algal production in lakes are the level of available nutrients (phosphorus and nitrogen, primarily), and the amount of light available in the water column for photosynthesis. Less common limiting factors in lakes, and other lentic waterbodies, include available levels of carbon,

iron, and certain trace elements (such as molybdenum or vitamins), as well as grazing pressure, temperature, or hydrologic flushing rate.

Nutrient ratios are commonly considered in determining which major plant nutrients are limiting factors in lakes. These ratios take into account the relative needs of algae for the different chemical elements versus availability in the environment. Typically, total nitrogen/total phosphorus (TN/TP) mass ratios above 10-12 indicate increasing phosphorus limitation. Conversely, TN/TP ratios of less than 7-10 indicate increasing importance of nitrogen. Ratios of 7-to-12 indicate that both nutrients, or neither, may limit algal production (Wetzel, 1983; Horne and Goldman, 1994).

Table 9 presents limiting factor determinations for the lakes surveyed during 2001. It should be kept in mind that these determinations reflect the time of sampling, which is chosen to reflect average conditions during the summer growing season to the extent possible, but may be less applicable to other times of the year. There is, however, always the chance that conditions during one survey will differ from conditions during past surveys, despite efforts to sample during times representative of "normal" summer conditions. If such a situation is suspected, it will be noted in Table 9 or elsewhere in the report.

As indicated in Table 9, phosphorus was the primary limiting factor identified for lakes surveyed in 2001, although nitrogen was almost equal in importance. Twelve of the 35 lakes (34%) were determined to be primarily limited by phosphorus. Ten lakes (29%) were determined to be primarily nitrogen limited. Three lakes were primarily light limited (9%). Another nine lakes (26%) were co-limited by phosphorus and nitrogen or limited by combinations of nutrients, micronutrients, and/or light availability. One lake (<3%) was determined to be limited by biological interactions with the macrophyte community.

In addition to nutrient ratios, the following six metrics are considered to help determine the relative roles of light and nutrient limitation for lakes in Kansas (Walker, 1986; Scheffer, 1998).

1)  $\text{Non-Algal Turbidity} = (1/\text{SD}) - (0.025 \text{ m}^2/\text{mg} \cdot \text{C})$ ,

where SD = Secchi depth in meters and C = chlorophyll-a in  $\text{mg}/\text{m}^3$ .

Non-algal turbidity values  $<0.4 \text{ m}^{-1}$  tend to indicate very low levels of suspended silt and/or clay, while values  $>1.0 \text{ m}^{-1}$  indicate that inorganic particles are important in creating turbidity. Values between 0.4 and  $1.0 \text{ m}^{-1}$  describe a range where inorganic turbidity assumes greater influence on water clarity as the value increases, but would not assume a significant limiting role until values exceed  $1.0 \text{ m}^{-1}$ .

Table 9. Limiting factor determinations for the 35 lakes surveyed during 2001. NAT = non-algal turbidity, TN/TP = nitrogen-to-phosphorus ratio,  $Z_{mix}$  = depth of mixed layer, Chl-a = chlorophyll-a, and SD = Secchi depth. N = nitrogen, P = phosphorus, and L = light. Shading = calculated light attenuation coefficient times mean lake depth.

Lake	TN/TP	NAT	$Z_{mix}$	Chl-a*SD	Chl-a/TP	$Z_{mix}/SD$	Shading	Factors
Atchison Co. SFL	4.0	0.33	0.80	26.32	0.43	2.34	3.92	N
Big Hill Lake	14.5	0.31	1.47	22.68	0.54	3.40	7.37	P>N
Bourbon Co. SFL	15.4	<0.05	<0.10	40.58	0.89	4.38	7.55	P≥N
Brown Co. SFL	2.7	0.09	0.16	38.22	0.34	3.66	5.39	N
Cowley Co. SFL	37.7	0.46	1.43	17.22	0.93	2.52	4.32	P
Elk City Lake	3.2	2.15	8.35	8.25	0.45	10.52	9.69	L=N
Eureka City Lake	11.9	0.25	0.77	32.29	0.59	3.97	6.33	P=N
Fall River Lake	2.5	2.83	7.97	2.64	0.12	8.54	6.46	L≥N
Gridley City Lake	2.5	1.00	1.43	15.16	0.35	2.30	2.85	N
Hillsdale Lake (whole lake)	11.7	0.47	2.33	21.38	0.58	5.00	9.17	P≥N
Hillsdale Lake Station 1	16.7	0.36	1.81	23.39	0.68	4.35	8.74	P>N
Hillsdale Lake Station 2	7.2	0.55	1.97	20.07	0.41	3.96	6.05	P=N
Hillsdale Lake Station 3	15.8	0.52	1.65	20.43	0.86	3.37	5.22	P=N
Kingman Co. SFL	32.2	0.41	0.24	7.60	0.15	0.30	0.85	Macrophytes
Kirwin Lake	17.2	0.09	0.42	34.58	0.42	3.08	7.52	P≥N
Lake Meade SFL	16.13	1.04	1.13	19.65	0.41	4.37	2.79	P≥N
Leavenworth Co. SFL	3.7	0.24	0.84	28.32	0.47	2.86	5.42	N

Lake	TN/TP	NAT	Z <sub>nut</sub> *NAT	Chl-a*SD	Chl-a/TP	Z <sub>nut</sub> /SD	Shading	Factors
Lovewell Lake	4.7	0.82	2.76	23.38	0.19	6.64	8.31	N
Marion Co. Lake	8.6	0.40	1.31	21.69	0.31	2.87	5.01	N>P
McPherson Co. SFL	6.3	<0.05	<0.10	79.71	0.65	4.27	9.29	N
Montgomery Co. SFL	14.5	<0.05	<0.10	45.76	0.99	4.67	7.61	P>N
Mound City Lake	16.1	0.49	1.10	21.72	0.52	2.41	3.69	P>N
Murray Gill Lake	40.5	0.21	0.85	13.28	0.42	1.27	4.32	P
Neosho Co. SFL	7.1	0.76	1.94	19.66	0.42	3.82	4.93	P=N
Norton Lake	12.4	0.45	1.89	19.26	0.21	3.65	6.56	N>P
Osage Co. SFL	22.2	0.57	2.16	8.41	0.20	2.74	4.84	P= Micronutrients
Pottawatomie Co. SFL #1	15.5	0.27	0.56	30.03	0.51	2.26	3.74	P>N
Pottawatomie Co. SFL #2	9.8	0.50	1.70	6.93	0.21	2.05	3.97	(N>P)≥ Micronutrients
Sedan South Lake	14.7	0.53	1.44	9.58	0.45	1.89	3.29	(P=N)> Micronutrients
Shawnee Mission Lake	9.3	0.19	0.67	14.36	0.22	1.04	3.51	N>P
Strowbridge Reservoir	20.4	0.94	2.91	9.52	0.29	3.82	4.81	P>L
Toronto Lake	3.7	2.68	5.24	4.65	0.22	5.93	4.71	L≥N
Wabunsee Co. Lake	10.8	0.67	2.42	13.35	0.45	3.63	5.47	P=N
Waconda Lake	33.7	0.43	2.48	13.42	0.29	3.74	9.14	P
Wellington City Lake	10.9	3.15	5.88	2.18	0.06	6.22	4.56	L

Lake	TN/TP	NAT	Z <sub>mix</sub> *NAT	Chl-a*SD	Chl-a/TP	Z <sub>mix</sub> /SD	Shading	Factors
Winfield City Lake	13.7	0.95	3.69	13.10	0.53	5.48	7.05	(P=N)>L
Woodson Co. SFL	8.8	0.51	2.23	12.04	0.35	3.19	5.98	P=N
Wyandotte Co. Lake	8.0	0.25	1.08	21.87	0.61	2.37	5.72	P=N

Criteria Table

Expected Lake Condition	TN/TP	NAT	Z <sub>mix</sub> *NAT	Chl-a*SD	Chl-a/TP	Z <sub>mix</sub> /SD	Shading
Phosphorus Limiting	>12				>0.40		
Nitrogen Limiting	<7				<0.13		
Light/Flushing Limited		>1.0	>6	<6	<0.13	>6	>16
High Algae-to-Nutrient Response		<0.4	<6	>16	>0.40	<6	
Low Algae-to-Nutrient Response		>1.0	>6	<6	<0.13	>6	>16
High Inorganic Turbidity		>1.0	>6	<6		>6	<16
Low Inorganic Turbidity		<0.4	<6	>16		<6	<16
High Light Availability			<6	>16		<6	<16
Low Light Availability			>6	<6		>6	>16

2) Light Availability in the Mixed Layer =  $Z_{\text{mix}} * \text{Non-Algal Turbidity}$ ,

where  $Z_{\text{mix}}$  = depth of the mixed layer, in meters, and non-algal turbidity.

Values <3 indicate abundant light, within the mixed layer of a lake, and a high potential algal response to nutrients. Values >6 indicate the opposite.

3) Partitioning of Light Extinction Between Algae and Non-Algal Turbidity =  $\text{Chl-a} * \text{SD}$ ,

where Chl-a = chlorophyll-a in  $\text{mg/m}^3$  and SD = Secchi depth in meters.

Values <6 indicate that inorganic turbidity dominates light extinction in the water column and there is a weak algal response to changes in nutrient levels. Values >16 indicate the opposite.

4) Algal Use of Phosphorus Supply =  $\text{Chl-a} / \text{TP}$ ,

where Chl-a = chlorophyll-a in  $\text{mg/m}^3$  and TP = total phosphorus in  $\text{mg/m}^3$ .

Values <0.13 indicate a low algal response to phosphorus, indicating that nitrogen, light, or other factors may be important. Values above 0.4 indicate a strong algal response to changes in phosphorus level. The range between 0.13-to-0.4 suggests a variable but moderate response by algae to phosphorus.

5) Light Availability in the Mixed Layer for a Given Surface Light =  $Z_{\text{mix}} / \text{SD}$ ,

where  $Z_{\text{mix}}$  = depth of the mixed layer, in meters, and SD = Secchi depth in meters.

Values <3 indicate that light availability is high and potential algal response to changes in nutrient levels is high. Values >6 indicate the opposite.

6) Shading in Water Column due to Algae and Inorganic Turbidity =  $Z_{\text{mean}} * E$ ,

where  $Z_{\text{mean}}$  = mean lake depth, in meters, and E = calculated light attenuation coefficient, in units of  $\text{m}^{-1}$ , derived from Secchi depth and chlorophyll-a data (Scheffer, 1998).

Values >16 indicate high levels of self-shading due to algae or inorganic turbidity in the water column. Values <16 indicate that self-shading of algae does not significantly impede productivity. The metric is most applicable to lakes with maximum depths less than 5 meters (Scheffer, 1998).

In addition to the preceding metrics, an approach put forth by Dr. Robert Carlson (1991) was used to test the limiting factor determinations made from the suite of metrics used in this, and previous, reports. The approach uses the Carlson trophic state indices for total phosphorus, chlorophyll-a, Secchi depth, and the newer index for total nitrogen. Index scores are calculated for each lake, then metrics are calculated for  $\text{TSI}_{(\text{Secchi})} - \text{TSI}_{(\text{Chl-a})}$  and for  $\text{TSI}_{(\text{TP or TN})} - \text{TSI}_{(\text{Chl-a})}$ . The degree of deviation of

each of these metrics from zero provides a measure of their potential limiting factors. In the case of the metric dealing with Secchi depth and chlorophyll, a positive difference indicates small particle turbidity is important, while a negative difference indicates that larger particles (zooplankton, algal colonies) exert more importance. In the case of the metric dealing with nutrients, a positive difference indicates the nutrient in question may not be the limiting factor, while a negative difference strengthens the assumption that the particular nutrient limits algal production and biomass. Differences of more than 5 units were used as the threshold for determining if the deviations were significantly different from zero. This approach generally produced the same determinations as those derived from the use of the suite of metrics. It clearly identified those lakes with extreme turbidity or those with algal colonies or large celled algal species.

In identifying the limiting factors for lakes, primary attention was given to the metrics calculated from 2001 data. However, past Secchi depth and chlorophyll-a data were also used in comparison to 2001 data. Additionally, mean and maximum lake depth were taken into account when ascribing the importance of non-algal turbidity. Lakes with fairly high non-algal turbidity may have little real impact from that turbidity if the entire water column rapidly circulates (Scheffer, 1998).

#### Surface Water Exceedences of State Water Quality Criteria

Most numeric and narrative water quality criteria referred to in this section are taken from the Kansas Administrative Regulations (K.A.R. 28-16-28b through K.A.R. 28-16-28f), or from EPA water quality criteria guidance documents (EPA, 1972, 1976; KDHE, 1999) for ambient waters and finished drinking water. Copies of the Standards may be obtained from the Bureau of Water, KDHE, 1000 Southwest Jackson Ave., Suite 420, Topeka, Kansas 66612.

Tables 11, 12, and 13 present documented exceedences of surface water quality criteria and goals during the 2001 sampling season. These data were generated by comparison of a computer data retrieval, for the 2001 Lake and Wetland Monitoring Program ambient data, to the state surface water quality standards and other federal guidelines. Only those samples collected from a depth of 3.0 meters, or less, were used to document standards violations, as a majority of those samples collected from below 3.0 meters were from hypolimnetic waters. In Kansas, lake hypolimnions generally constitute a small percentage of total lake volume and, while usually having more pollutants present in measurable quantities, compared to overlying waters, do not generally pose a significant water quality problem for the lake as a whole.

Eutrophication criteria in the Kansas Surface Water Quality Standards are narrative rather than numeric. This is partially due to the fact that the trophic state of any individual lake reflects a number of site-specific and regional environmental characteristics, combined with pollutant inputs from its watershed. However, lake trophic state does exert a documented impact on various lake uses. The system on the following page (Table 10) has been developed over the last ten years to define how lake trophic status influences

Table 10. Lake use support determination based on lake trophic state (Also see the Appendix.)

Designated Use	A	M	SE	E	VE	H-no BG TSI 64-70	H-no BG TSI 70+	H-with BG TSI 64+
Aquatic Life Support	X	Full	Full	Full	Partial	Partial	Non	Non
Drinking Water Supply	X	Full	Full	Partial	Partial	Non	Non	Non
Primary Contact Recreation	X	Full	Full	Partial	Partial	Non	Non	Non
Secondary Contact Recreation	X	Full	Full	Full	Partial	Partial	Non	Non
Livestock Water Supply	X	Full	Full	Full	Partial	Partial	Non	Non
Irrigation	X	Full	Full	Full	Partial	Partial	Non	Non
Groundwater Recharge								
Food Procurement								

Trophic state is not generally applicable to this use.

Trophic state is applicable to this use, but not directly.

BG = blue-green algae dominate the community (50%+ as cell count-and/or 33%+ as biovolume)  
X = use support assessment based on nutrient load and water clarity, not algal biomass

A = argillotrophic (high turbidity lake)

M = mesotrophic (includes OM, oligo-mesotrophic, class), TSI = zero-to-49.9

SE = slightly eutrophic, TSI = 50-to-54.9

E = eutrophic (fully eutrophic), TSI = 55-to-59.9

VE = very eutrophic, TSI = 60-to-63.9

H = hypereutrophic, TSI ≥ 64

TSI = 64 = chlorophyll-a of 30 ug/L

TSI = 70 = chlorophyll-a of 56 ug/L

the various designated uses of Kansas lakes (EPA, 1990; NALMS, 1992). These trophic state/use support combinations are joined with the site-specific lake trophic state designations to determine expected use support levels at each lake. See the report appendix for an updated comparison of these trophic class based assessments versus risk based values developed over the last four years.

With respect to the aquatic life support use, eutrophication, high pH, and low dissolved oxygen within the upper 3.0 meters comprised the primary water quality concerns during 2001 (Table 11). Sixteen lakes exhibited trophic states high enough to impair long or short term aquatic life support. Sixteen lakes had low dissolved oxygen conditions within the top 3.0 meters of the water column. Eight lakes had pH levels high enough to impact aquatic life support. One lake in 2000 exhibited atrazine levels high enough to exceed the chronic aquatic life support criterion (3.0 ppb). Three lakes exhibited such high chronic turbidity that community structure and function were deemed adversely impacted.

The summer of 2001 experienced a longer period of intense heat than is typical of most summers. This created an unusual situation reflected in 11 lakes with surface water temperatures greater than 30° C. While not directly a result of human activity, these high water temperatures undoubtedly contributed to impacts on lake trophic state and aquatic life support.

Eutrophication exceedences are primarily due to excessive nutrient inputs from lake watersheds. Dissolved oxygen problems are generally due to advanced trophic state, which causes rapid oxygen depletion below the thermocline, but were also observed in lakes that did not exhibit excessive trophic state conditions. In these cases, the low dissolved oxygen levels likely resulted from shallow stratification conditions. Lakes with elevated pH are also reflective of high trophic state and algal production.

There were 28 exceedences of water supply criteria and/or guidelines during 2001 (Table 12). The majority were for eutrophication related conditions (93%). Of these 28 exceedences, only 12 (43%) occurred in lakes that currently serve as public water supplies. Irrigation use criteria were exceeded in 16 lakes, only two of which currently are designated for irrigation supply. Livestock water criteria were exceeded in 16 lakes, none of which is currently a livestock water source. Human health criteria for mercury were exceeded in one lake.

Table 13 lists 26 lakes with trophic state/turbidity conditions high enough to impair contact recreational uses. Seventeen of the lakes surveyed had high enough trophic state or turbidity to impair secondary contact recreation during 2001.

In all, there were 187 exceedences of numeric or narrative criteria, water quality goals, or EPA guidelines documented in Kansas lakes during 2001. Of these, 43% related to aquatic life support, 33% related to consumptive uses, and 24% related to recreational uses. A total of 75% of these exceedences occurred in lakes designated for the particular uses, while 25% occurred in lakes where uses have not yet been verified through use attainability analyses.

Table 11. Chemical and biological parameters not complying with chronic and acute aquatic life support (ALS) criteria in lakes surveyed during 2001. Atz = atrazine, DO = dissolved oxygen, EN = eutrophication or high nutrient load, and TN = high turbidity and nutrient load. Only those lakes with some documented water quality problem are included in Tables 11, 12, and 13.

Lake	Chronic ALS							Acute ALS				
	EN*	TN*	pH*	DO*	Hg	Pb	Atz	EN*	TN*	pH*	DO*	High Temp.
Atchison Co. SFL	X		X	X			X			X	X	X
Bourbon Co. SFL	X		X	X				X		X	X	X
Brown Co. SFL	X		X	X				X		X	X	X
Elk City Lake	X											X
Eureka City Lake	X											
Fall River Lake		X		X							X	X
Gridley City Lake	X			X							X	X
Hillsdale Lake	X											
Kingman Co. SFL			X			X				X		
Kirwin Lake	X			X								
Lake Meade SFL (see footnote)	X		(X)	(X)				X		(X)	(X)	(X)
Leavenworth Co. SFL	X											
Lovewell Lake	X		X					X		X		
Marion Co. Lake				X								
McPherson Co. SFL	X		X					X		X		

	Chronic ALS							Acute ALS				
	EN*	TN*	pH*	DO*	Hg	Pb	Atz	EN*	TN*	pH*	DO*	High Temp.
Montgomery Co. SFL	X		X	X				X		X	X	X
Mound City Lake	X			X								
Murray Gill Lake												
Neosho Co. SFL	X			X	X							X
Norton Lake			X	X						X		
Pottawatomie Co. SFL #1	X			X				X			X	
Pottawatomie Co. SFL #2												
Sedan South Lake				X								X
Shawnee Mission Lake				X								
Toronto Lake		X		X								X
Wellington City Lake		X							X			
Wyandotte Co. Lake				X								X

\* = Although there are no specific chronic versus acute criteria for these parameters, the magnitude of the excursions are used to determine whether the impact is immediate or of a more long term importance.

Lake Meade SFL = Although not counted towards exceedence totals for this report, this lake's trophic state and past water quality suggests high pH, low dissolved oxygen, and high surface water temperatures would be present for much of the summer of 2001. The sampling in 2001, for this lake, did not include these parameters because it was specific towards documenting nutrient loads and levels for TMDL development.

Table 12. Exceedence of human use criteria and/or EPA guidelines within the surface waters of the lakes surveyed during 2001. Atz = atrazine and EN = high trophic state or nutrient loads. Only lakes with documented exceedences are included within the table. An "X" indicates that the exceedence occurred for a presently designated use. An "(X)" indicates that the exceedence occurred where the indicated use has not yet been verified.

Lake	Water Supply			Irrigation	Livestock Water	Human Health
	EN	SO <sub>4</sub>	Atz	EN	EN	Hg
Atchison Co. SFL	(X)		(X)	(X)	(X)	
Big Hill Lake	X					
Bourbon Co. SFL	(X)			(X)	(X)	
Brown Co. SFL	(X)			(X)	(X)	
Cowley Co. SFL	(X)					
Elk City Lake	X			(X)	(X)	
Eureka City Lake	X			(X)	(X)	
Fall River Lake	X					
Gridley City Lake	(X)			(X)	(X)	
Hillsdale Lake	X			(X)	(X)	
Kirwin Lake	(X)			X	(X)	
Lake Meade SFL	(X)			(X)	(X)	
Leavenworth Co. SFL	(X)			(X)	(X)	
Lovewell Lake	(X)			X	(X)	
Marion Co. Lake	(X)					
McPherson Co. SFL	(X)			(X)	(X)	
Montgomery Co. SFL	(X)			(X)	(X)	
Mound City Lake	X			(X)	(X)	
Neosho Co. SFL	(X)			(X)	(X)	X
Norton Lake	X					
Pottawatomie Co. SFL #1	(X)			(X)	(X)	
Toronto Lake	X					

Lake	Water Supply			Irrigation	Livestock Water	Human Health
	EN	SO <sub>4</sub>	Atz	EN	EN	Hg
Wabaunsee Co. Lake	X					
Waconda Lake		X				
Wellington City Lake	X					
Winfield City Lake	X					
Wyandotte Co. Lake	(X)					

Table 13. Exceedences of numeric and narrative recreational guidelines for lakes surveyed during 2001. Primary contact recreation refers to recreation where ingestion of lake water is likely. Secondary contact recreation involves a low likelihood of accidental ingestion of lake water. EN = high trophic state or nutrient loads and TN = high turbidity and nutrient loads. An "X" indicates that a use attainability study has been completed and/or the use was previously designated for that lake. Only lakes with impairments are listed.

Lake	Primary Contact Recreation		Secondary Contact Recreation	
	EN	TN	EN	TN
Atchison Co. SFL	X		X	
Big Hill Lake	X			
Bourbon Co. SFL	X		X	
Brown Co. SFL	X		X	
Cowley Co. SFL	X			
Elk City Lake	X		X	
Eureka City Lake	X		X	
Fall River Lake	X	X		
Gridley City Lake	X		X	
Hillsdale Lake	X		X	
Kirwin Lake	X		X	
Lake Meade SFL	X		X	
Leavenworth Co. SFL	X		X	
Lovewell Lake	X		X	
Marion Co. Lake	X			
McPherson Co. SFL	X		X	
Montgomery Co. SFL	X		X	
Mound City Lake	X		X	
Neosho Co. SFL	X		X	
Norton Lake	X			
Pottawatomie Co. SFL #1	X		X	
Toronto Lake	X	X		

Lake	Primary Contact Recreation		Secondary Contact Recreation	
	EN	TN	EN	TN
Wabaunsee Co. Lake	X			
Wellington City Lake	X	X		X
Winfield City Lake	X			
Wyandotte Co. Lake	X			

### Pesticides in Kansas Lakes, 2001

Detectable levels of at least one pesticide were documented in the main body of 20 lakes sampled in 2001 (59% of lakes surveyed for pesticides). Table 14 lists these lakes and the pesticides that were detected, along with the level measured and the analytical quantification limit. Four different pesticides, and two pesticide degradation byproducts, were noted in 2001. Of these six compounds, atrazine, alachlor, and diazinon currently have numeric criteria in place for aquatic life support and/or water supply uses (KDHE, 1999).

Atrazine continues to be the pesticide detected most often in Kansas lakes (KDHE, 1991). Atrazine, and the atrazine degradation byproduct deethylatrazine, accounted for 78% of the total number of pesticide detections, and atrazine was detected in 19 of the 20 lakes. In addition to atrazine, four lakes had detectable levels of metolachlor (Dual), one had detectable levels of alachlor (Lasso), and one had detectable levels of diazinon (Spectracide). Six lakes and one lake, respectively, had detectable quantities of the atrazine degradation byproducts deethylatrazine and deisopropylatrazine.

In almost all cases, the presence of these pesticides was directly attributable to agricultural activity. In the case of Shawnee Mission Lake, diazinon likely represents house and urban garden application. In Atchison Co. SFL, atrazine concentrations exceeded the chronic aquatic life support and drinking water supply criteria. This lake is not designated for public water supply, however. Based on the number of different pesticides detected, Wellington City Lake and Strowbridge Reservoir are of most concern. In terms of total maximum concentrations, Wellington City Lake, Strowbridge Reservoir, Brown Co. SFL, and Atchison Co. SFL would be of most concern..

Table 14. Pesticides levels documented during 2001 in Kansas lakes. All values listed are in ug/L. Analytical quantification limits are as follows: atrazine = 0.3 ug/L, deethylatrazine = 0.3 ug/L, deisopropylatrazine = 0.3 ug/L, metolachlor = 0.25 ug/L, alachlor = 0.1 ug/L, and diazinon = 0.01 ug/L. Only those lakes with detectable levels of pesticides are reported.

Lake	Pesticide					
	Atrazine	Deethyl-atrazine	Deisopropyl-atrazine	Metolachlor	Alachlor	Diazinon
Atchison Co. SFL	3.40	0.50				
Big Hill Lake	0.71					
Brown Co. SFL	2.40	0.42				
Elk City Lake	1.30					
Gridley City Lake	0.55	0.31				
Hillsdale Lake	1.60	0.32				
Kirwin Lake	0.33					
Lovewell Lake	1.30			0.29		
Marion Co. Lake	0.67					
McPherson Co. SFL	1.00			0.42		
Norton Lake	0.41					
Osage Co. SFL	1.00				0.27	
Shawnee Mission Lake						0.05
Strowbridge Reservoir	2.40	0.42		0.31		
Toronto Lake	0.46					
Waconda Lake	1.60			0.45		
Wellington City Lake	1.70	0.84	0.50			
Winfield City Lake	0.62					
Woodson Co. SFL	0.81					
Wyandotte Co. Lake	0.37					

### Discussion of Nonpoint Sources of Pollution for Selected Lakes

Nine lakes were chosen for further discussion, based on the number and type of observed surface water quality impacts. A waterbody was chosen if 1) three, or more, parameters exceeded their respective chronic aquatic life support criteria/guidelines, 2) more than two parameters exceeded applicable acute aquatic life support criteria/guidelines, or 3) more than one parameter exceeded irrigation, water supply, livestock watering, or recreational criteria. Possible causes and sources of these documented water quality problems are considered below. The nine selected lakes fell into two distinct categories. Therefore, rather than discussing each lake separately, discussion will focus on the groups.

Group one includes six lakes (Atchison Co. SFL, Bourbon Co. SFL, Brown Co. SFL, Lake Meade SFL, Montgomery Co. SFL, and Neosho Co. SFL). All six show impairments related to excessive nutrient loads and high trophic state development. Besides over production of algal biomass, secondary impacts such as high pH and low dissolved oxygen are frequently observed. These conditions result in the impairment of most recreational, aquatic life support, and fisheries uses. Atchison and Brown Co. SFLs have abundant portions of their respective watersheds in agricultural cropland. Montgomery, Neosho, and Lake Meade SFLs have less contributing cropland in their watersheds, but still have histories of eutrophication problems. Their conditions derive from nutrients from other sources (pasture and livestock) combined with in-lake features (i.e., Neosho Co. SFL is fairly shallow, Lake Meade SFL is shallow and has hydrologic problems). Bourbon Co. SFL was not typical of historic condition during 2001. Normally, the trophic status of Bourbon Co. SFL is eutrophic or lower. Owing to the heat and dry weather in 2001, the results from Bourbon Co. SFL may not reflect long term condition.

Group two includes three lakes (Fall River Lake, Toronto Lake, and Wellington City Lake). All three show problems related to high turbidity. All three have histories of high turbidity, although Wellington City Lake shows far more impairment in this area than do the others. All three lakes have significant amounts of cropland within their drainages as sediment sources. However, all three have sizeable areas of shallow water within them and wind resuspension is likely in all three. The role of benthic feeding fish (i.e., common carp) is unknown but may have some importance in Wellington City Lake.

### Taste and Odor/Algal Bloom Investigations During 2001

From January 1, 2001, to January 1, 2002, eleven investigations were undertaken within the auspices of the KDHE Taste & Odor/Algae Bloom Program. The results of these investigation are discussed below. Four of the investigations dealt with fishkills, three primarily with aesthetic complaints, three were related to treatment lagoons, and one was related to finished drinking water quality.

On January 17, 2001, staff from the KDHE Southcentral office investigated a fishkill on the Arkansas River in Wichita, Kansas, in the vicinity of Central Street. The fishkill was species

specific, only involving gizzard shad (*Dorosoma cepedianum*), and followed the river being frozen then thawed by several warm afternoons. Dissolved oxygen was high (11.2 mg/L) by the time of the investigation, which took place in the afternoon. Algae samples showed a small, mixed, community along the length of river investigated. Natural causes (most likely thermal stresses) were believed the ultimate cause of the fishkill.

Throughout 2001, staff from the KDHE Southcentral office have submitted lagoon effluent samples from the Burrton, Kansas, facility for algal analysis as part of a special study being conducted by the KDHE Bureau of Water. Although showing some seasonal variation, the lagoon effluent frequently displayed numbers and biovolumes elevated even for a wastewater treatment lagoon. Community composition in the spring was dominated by green and cryptophyte algae. By summer, and into the fall, blue-green species became dominant and accompanied the higher cell counts and biovolumes.

On May 30, 2001, staff from the KDHE Northeast office submitted algae samples from Franklin County Rural Water District #6, related to high turbidity in finished drinking water and a bright green coloration of the presedimentation basin. These samples were in response to problems, over the previous two years, with elevated turbidity in finished drinking water. The raw water, from the Marais des Cygnes River, contained a moderate community of green and diatom algae species. The algae community from the presedimentation basin was considerably larger, however, and contained the added feature of a significant *Pediastrum* sp. population. This green colonial algae was almost certainly the cause of the described color in the presedimentation basin. Many species of diatoms can produce fishy odors and generally cause water treatment process difficulties. These were the most probable cause of the reported odor in the raw water, although the *Pediastrum* sp. bloom may have also contributed. It was indicated that the Rural Water District intended to begin prechlorination in the near future to attempt correction of the problem.

On June 8, 2001, Staff from the KDHE Southcentral office collected algae samples as part of a fishkill investigation at Cambridge Apartments Lakes in Wichita, Kansas. The algae sample contained a small community of green and diatom algae, but the investigation did not occur until after a storm event passed through the area. It is very likely the storm runoff made the samples unrepresentative of the water quality at the time of the fishkill.

On June 14, 2001, staff from the KDHE Southcentral office submitted algae samples from the Longbranch Mobile Home Park wastewater lagoons in Wichita, Kansas. The samples indicated the presence of an excessively large blue-green algae community, even for a wastewater treatment lagoon. Chlorophyll-a, estimated from biovolume, was predicted to be >1,000 ppb, suggestive of an overloaded lagoon.

On July 26, 2001, staff from the KDHE Northeast office and the Bureau of Environmental Field Services jointly investigated a fishkill and aesthetic complaint at Myer's Pond in southeast Topeka, Kansas. This small lake, which has a number of homes along one shore, has been the site of frequent fishkills and complaints over the years. Samples collected during the investigation indicated a very large blue-green algae community and anoxic early morning conditions (dissolved oxygen = 0.2

mg/L). Residents were cautioned to avoid contact with the water until the bloom condition was gone. The ultimate source of the problem is the nutrient load from Shawnee Co. Sewer District #8, whose lagoon discharge enters the upstream end of the lake. Myer's Pond was included in a study in the mid 1990s, designed to look at the effects of small point source discharges on small lakes. The study concluded that, even if the lagoon discharge were to cease, which it is ultimately supposed to do, it would take many years to deplete the sediment nutrients that have built up over time.

On August 22, 2001, staff from the KDHE Southcentral office submitted algae samples as part of a fishkill investigation at Cheney Lake in Reno and Sedgwick Counties. These samples indicated a fairly large blue-green algae community in the lake, which is atypical. Cheney Lake is a chronically turbid system and is light limited in terms of algal production. Over the last few years, water supply problems at Cheney Lake, related to tastes and odors, coincide with periods of calm winds/weather. These calm periods allow the water column to become clearer, resulting in temporary blue-green algae blooms. While the observed algae bloom was moderately large at the time of the fishkill, it is believed that it was less of a factor in the fishkill than the antecedent extreme heat and high water temperatures that had been occurring. Water temperatures of 36-37° C were documented at the time of the investigation, and had likely been present for some time.

On September 4, 2001, staff from the KDHE Northeast office collected algae samples related to a complaint at the Sabetha, Kansas, Country Club Lake. This lake has had very high trophic state problems in the past, and has a number of nutrient sources besides being next to a golf course. The collected algae samples indicated a very large blue-green algae community with a thick surface scum, which was the primary cause of the complaints. Controls on nearby feedlot runoff, and the elimination of a discharge from a septic system, were begun in an attempt to reverse the situation at this lake. It was advised that people be cautioned about contacting the water until the bloom condition ended.

On September 5, 2001, staff from the KDHE Northeast office submitted algae samples from an unspecified household wastewater lagoon for analysis. The lagoon, newly built and put into operation, developed a bright red surface scum, with a very bright green coloration under the surface layer. The algae was a species of green algae, believed to be in the genus *Haematococcus* spp. Although striking and disconcerting to the home owners, the algae bloom was likely part of the process of this new lagoon reaching some sort of equilibrium.

On November 7, 2001, staff from the KDHE Southcentral office submitted algae samples related to an aesthetic complaint at Lakeside Acres Lake, several miles east of Hutchinson, Kansas. The complaint was regarding a blue-green surface scum collecting on the down wind shore of the lake. The algae samples indicated the presence of a very large bloom of the blue-green algae *Microcystis aeruginosa*. Given the nature of the algae bloom, district staff were advised that residents should be cautioned to avoid any body contact with the lake, keep children and pets away from it, and do so until the bloom was completely gone.

On November 19, 2001, staff from the KDHE Southcentral office submitted algae samples related to an aesthetic complaint in Chisholm Creek, upstream from metropolitan Wichita, Kansas. Water in Chisholm Creek had a striking red coloration, with a red scum at the surface. Examination of the samples revealed that algae were not the cause of the coloration. Rather the red scum was a fairly large population of a small flagellated protozoan. Each protozoan had 2-5 round, red objects within them. Further examination of the samples indicated that these small, red, spheres were not organelles of the protists but ingested objects, most likely coccoid bacteria. Organic debris in the samples had numerous quantities of the red spheres present on the outer surfaces. It was surmised that the red scum was the result of protozoans eating these red organisms at the substrate interface, then swimming to the stream surface. At the time of the complaint, Chisholm Creek was very stagnant and enriched with leaf litter.

## CONCLUSIONS

The following conclusions are based on the lake monitoring data collected during 2001.

- 1) Trophic state data indicated that 37% of the lakes surveyed in 2001 had degraded, compared to their historic mean condition (i.e., their trophic state had increased). About 54% showed stable conditions over time, and 9% showed improved trophic state condition.
- 2) Over 65% of the documented water quality impairments in these lakes were associated with high lake trophic status. Other problems included low dissolved oxygen, high pH, atrazine, sulphate, and high turbidity. Lake trophic state problems resulted primarily from excessive nutrient inputs from nonpoint sources, exacerbated by the long, hot summer weather conditions during much of the summer of 2001.
- 3) Twenty of the 34 lakes surveyed for pesticides (59%) had detectable levels of agricultural and home use pesticides. As noted in previous years, atrazine was the most frequently detected pesticide. However, most detections were below applicable water quality criteria. Both the lower pesticide levels, and the lower number of total criteria exceedences, likely resulted from the extended dry conditions experienced during the summer of 2001, as also happened in the summer of 2000.

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## LAKE DATA AVAILABILITY

Water quality data are available for all lakes included in the Kansas Lake and Wetland Monitoring Program. These data may be requested by writing to the Bureau of Environmental Field Services, KDHE, 1000 Southwest Jackson Ave., Suite 430, Topeka, Kansas 66612-1367.

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## APPENDIX A: Lake Trophic State Visual Assessments

### INTRODUCTION

The last few years have seen a nationwide movement to accelerate the development of lake/reservoir eutrophication standards. EPA is now in the process of developing ecoregional nutrient criteria that the states will have to adopt, or face having them promulgated by EPA on their behalf (EPA, 1998). There is fairly unanimous scientific opinion that higher lake trophic state does correspond with increasing levels of lake use impairment (e.g.; EPA, 1990; NALMS, 1992; KDHE, 1998a; KDHE, 1998b). A number of states currently have narrative eutrophication criteria in their water quality standards, and several states and Canadian provinces have developed numeric eutrophication criteria (EPA, 1990; NALMS, 1992). A study published in 1989 indicated that about 60% of the states indicate they have a need for numeric eutrophication criteria (Johnson, 1989). A number of recent studies have also indicated a strong connection between increasing lake trophic state and loss of economic revenues from lakes (e.g.; Boyle, et. al., 1997; Jobin, 1997).

Kansas has had a narrative eutrophication criterion in its water quality standards for many years. For the last four 305(b) reporting cycles, lake trophic state classification has been used to apply this narrative criterion in assessments of lake use impairment. The validity and value of using non-regulatory numeric criteria to implement a regulatory narrative criterion has been recognized by experts in the area of eutrophication management (Heiskary and Walker, 1988; NALMS, 1992) and is encouraged by the EPA in many of their guidance documents. Table 10 compiles the system that has been used and referenced in recent KDHE documents (KDHE, 1998a; KDHE, 1998b). This system has been derived largely from the standards developed in other states, incorporating those ideas and concepts that are best suited to our geographic region.

In 1998, KDHE staff began a project to collect data that might provide refined threshold levels for determining lake use impairments based on trophic state and water clarity. The 1998 annual report presented the results of that first effort. During 1999 and 2000, data collection efforts continued and the combined data from 1998-1999 were presented in the 1999 program report. Continuing in that same manner, the combined 1998-2001 data are analyzed and presented in this report.

### METHODS

During the summers of 1998-2001, KDHE attempted to verify the suitability of the numeric guidelines presented in Table 10 for assessing lake use impairment by eutrophication. The methodology was developed for use in Minnesota, where lake conditions are described in terms of the frequency, or risk of, nuisance conditions (Heiskary and Walker, 1988). The reader is referred to that article for an in-depth discussion of procedures. The basic method involves 1) *a-priori* assessments of lake use support, based on visual inspection, 2) correlating visual assessment data with analytical data for trophic state parameters (nutrients, chlorophyll-a, Secchi depth, and non-algal

turbidity), 3) conducting a frequency analysis of the data, and 4) using that frequency analysis to develop criteria based on perceived risk levels (<1%, 10%, 25%, etc.).

Three lake uses were assessed for the study conducted in 1998-2001. These were primary contact recreation, secondary contact recreation (formerly designated non-contact recreation), and aesthetic use. Kansas water quality standards do not recognize an "aesthetic" use for surface waters, unlike some neighboring states such as Nebraska. Nevertheless, the aesthetic quality of lakes does exert an impact on other types of use support and even property values (Boyle, et al., 1997). In Kansas, many housing projects have used their location near a lake to attract buyers. Lowered water quality in these lakes does have an impact on property buyers and property values. "Aesthetic" assessment of the water, for this study, looked for a presence or absence of an overtly visible algae community and inorganic turbidity. While the model for this effort (Heiskary and Walker, 1988) used frequency analysis to derive phosphorus criteria, KDHE chose to derive primary criteria for algal biomass, water clarity, and total phosphorus. The first two criteria should be utilized as the primary indicators of lake use support, although total phosphorus criteria will be of primary importance in both TMDL work and in describing downstream impacts.

While the Minnesota approach utilized only a single visual assessment, focusing on the level of "green" observed in the water, KDHE's study involved two separate assessments, "green" and "brown." These visual assessments relate to impairments resulting from elevated lake trophic state (algal biomass) and reduced levels of water clarity, respectively. In Kansas (and throughout much of the world), traditional water clarity measures, such as Secchi depth and nephelometric turbidity, are influenced more by soil-derived inorganic turbidity than by algae (Davies-Colley, et al., 1993). Given that soil erosion is a major problem in many Kansas watersheds, the use of two visual assessments was deemed valuable.

Staff of the Lake and Wetland Monitoring Program conducted visual assessments at each waterbody surveyed during the summers of 1998-2001. This resulted in 2,580 observational scores being included in the values generated for this report. At each site, staff would first measure Secchi depth. The visual assessments were conducted by examining the color of the water upon the white quarters of the Secchi disk, at the shallower of a depth of one-half the measured Secchi depth or one meter. After examining the color of the water in this manner, plus assessing the overall appearance of the water column, "green" and "brown" scores were assessed by each staff member for each of the three use categories. The make-up of the field crew was believed to provide a decent cross-section of viewpoints, in that half of those involved had grown up in an urban setting in eastern Kansas while the other half had grown up in a rural western Kansas environment. While this study did not involve a random cross section of the general public, it did provide a valid data base for water quality standards development based on the recommendations of other entities involved in such efforts (Smeltzer and Heiskary, 1990; NALMS, 1992). Assigned scores rarely differed among field staff by more than one unit, demonstrating a general uniformity of perception among informed observers regardless of background. Fully 95% of scores matched exactly, or differed by only one point on a scale of one-to-ten.

Table A1 presents the system for assigning green scores, while Table A2 presents the system for assessing brown scores. In each case, a score of three is meant to represent the onset of minor use impairment (i.e., partial impairment) while a score of five is meant to represent the onset of significant use impairment (i.e., non-support). Only the green or brown quality of the water column was taken into account in assigning scores. The effects of water depth on primary contact recreation, shoreline condition on aesthetic appeal of the lake, lack of a boat ramp on boating, and other such factors were not considered in this exercise.

Table A1. "Green" score descriptors for primary and secondary contact recreational uses, and for aesthetics. Even scores allowed for maximum flexibility in allowing individuals to interpolate between descriptions. Hesitation about recreating in a given waterbody is based only on the appearance of the water, in terms of algae or "green-ness." Other factors, such as waterbody depth or presence of facilities, were not part of the assessment.

Score	Aesthetic Appearance	Primary Contact Recreation	Secondary Contact Recreation
1	Beautiful, no problems.	Beautiful, no problems.	Beautiful, no problems.
2			
3	Not clear. Some algae and color visible.	Slight hesitation about swimming in or contacting water.	Slight hesitation about wading or general recreation.
4			
5	Definite or strong green algae color.	Definite hesitation about swimming in or contacting water.	Definite hesitation about wading. Some reduced general recreation quality.
6			
7	Very strong green algae color.	Strong hesitation about swimming in or contacting water.	Strong hesitation about wading. Quality of general recreation definitely impaired.
8			
9	Extreme green algae color. Scums and/or odors evident.	Primary contact recreational use enjoyment impossible due to algae levels.	Wading and recreation enjoyment almost impossible due to algae.
10			

The frequency/risk potential approach was applied to both sets of scores, for all three uses. The water quality parameters of chlorophyll-a and Secchi depth were used in association with the green visual scores based on a high level of correlation between green visual scores and measured parameters. In a similar fashion, Secchi depth and calculated non-algal turbidity were used in association with brown visual scores based on a high correlation level between brown visual scores and these parameters. Total phosphorus was also examined, in comparison to both green and brown scores, as the original Minnesota study had done. For both brown and green scores, the strength of correlation with total phosphorus was less than for Secchi depth or chlorophyll-a, respectively, but still significant.

Table A2. "Brown" score descriptors for primary and secondary contact recreational uses, and for aesthetics. Even scores allowed for maximum flexibility in allowing individuals to interpolate between descriptions. Hesitation about recreating in a given waterbody is based only on the appearance of the water, in terms of turbidity or "brown-ness." Other factors, such as waterbody depth or presence of facilities, were not part of the assessment.

Score	Aesthetic Appearance	Primary Contact Recreation	Secondary Contact Recreation
1	Beautiful, no problems.	Beautiful, no problems.	Beautiful, no problems.
2			
3	Not clear. Some turbidity and color visible.	Slight hesitation about swimming in or contacting water.	Slight hesitation about wading or general recreation.
4			
5	Definite or strong turbidity/brown color.	Definite hesitation about swimming in or contacting water.	Definite hesitation about wading. Some reduced general recreation quality.
6			
7	Very strong brown turbidity/color.	Strong hesitation about swimming in or contacting water.	Strong hesitation about wading. Quality of general recreation definitely impaired.
8			
9	Extreme brown turbidity/color.	Primary contact recreational use enjoyment impossible due to turbidity levels.	Wading and recreation enjoyment almost impossible due to turbidity.
10			

## RESULTS

### Combined 1998-2001 Results

#### "Green" Scores

Three parameters were examined in comparison to the "green" criteria scores, including total phosphorus, chlorophyll-a, and Secchi depth. In the case of Secchi depth, the criteria values discussed in this report section should be applied to lakes that lack overtly visible levels of inorganic turbidity. Table A3 is concerned with lake trophic state (chlorophyll-a levels), Table A4 with in-lake total phosphorus, and Table A5 with Secchi depth.

Table A3. A comparison of use support versus current interpretation of lake trophic state and 1998-2001 *a priori* "green" data. All values are in units of ug/L, or ppb, of chlorophyll-a, rounded to the nearest full unit. The "risks" are the chlorophyll-a threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use.

Lake Use and Support Level	Current Method (trophic state) (chlorophyll-a ppb)	Risk Based Criteria 1998-2001 Green Data	
		<1%	10%
<b>Aesthetic Use</b> Physical Appearance			
Full Support	<12*	<2	<6
Partial Support	<12*	2-6	6-12
Non-Support	>12*	>6	>12
<b>Primary Contact</b> Recreational Use			
Full Support	<12	<9	<10
Partial Support	12-20	9	10-23
Non-Support	>20	>9	>23
<b>Secondary Contact</b> Recreational Use			
Full Support	<20	<9	<20
Partial Support	20-56	9-23	20-39
Non-Support	>56	>23	>39

\* = Aesthetic uses are not currently recognized under the Kansas Surface Water Quality Standards (K.A.R. 28-16-28b et seq).

Table A4. A comparison of use support versus current interpretation of in-lake total phosphorus and 1998-2001 *a priori* “green” data. All values are in units of ug/L, or ppb, of total phosphorus. The “risks” are the total phosphorus threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use.

Lake Use and Support Level	Current Method (trophic state) (total phosphorus ppb)*	Risk Based Criteria 1998-2001 Green Data	
		<1%	10%
Aesthetic Use Physical Appearance			
Full Support	<25	<15	<15
Partial Support	<25	15	15-30
Non-Support	>25	>15	>30
Primary Contact Recreational Use			
Full Support	<25	<15	<21
Partial Support	25-50	15	21-45
Non-Support	>50	>15	>45
Secondary Contact Recreational Use			
Full Support	<50	<15	<44
Partial Support	50-100	15-50	44-101
Non-Support	>100	>50	>101

\* = These values come from the EPA “Red Book” and have been used as general guidelines and goals for lakes in Kansas. They have not been used in previous use support assessments.

Table A3 indicates that the use of the distinct trophic state classes for use impairment assessment is a valid method. The greatest discrepancies are in the threshold for non-support of secondary contact recreation, and in the full-support threshold of aesthetic appearance, where current methodology is overly high at a 10% risk level. In these two areas, the current methodology equates with a 30-to-40% and a 55-to-65% risk level, respectively.

Table A4 indicates that, in terms of in-lake total phosphorus, the values published as guidelines for lakes and streams by the EPA back in the 1970s (EPA; 1972, 1976) are very representative of a 10% impairment risk level. The original EPA criteria/goals for total phosphorus were 25 ppb for lakes, 50 ppb for streams entering lakes, and 100 ppb for streams. KDHE has, historically, interpreted these for the Midwest as 25 ppb for open, deep water, 50 ppb for smaller, shallower reservoirs and upper reaches of large reservoirs, and 100 ppb for streams.

**Table A5.** A comparison of use support versus current interpretation of lake water clarity and 1998-2001 *a priori* “green” data. All values are in units of centimeters, or cm, of Secchi depth. The “risks” are the Secchi depth threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use. These table values should only be applied to lakes without overt inorganic turbidity.

Lake Use and Support Level	Current Method (trophic state) (Secchi Depth in cm)*	Risk Based Criteria 1998-2001 Green Data	
		<1%	10%
<b>Aesthetic Use Physical Appearance</b>			
Full Support	>100	>252	>252
Partial Support	>100	252	252-165
Non-Support	<100	<252	<165
<b>Primary Contact Recreational Use</b>			
Full Support	>70	>252	>213
Partial Support	>70	252-102	213-97
Non-Support	<70	<102	<97
<b>Secondary Contact Recreational Use</b>			
Full Support	no assessment value	>102	>97
Partial Support	no assessment value	102-88	97-57
Non-Support	no assessment value	<88	<57

\* = These Secchi depth values have been used as goals and guidelines for Kansas lakes, based on best professional judgement and the literature. They have not been used to previously assess lake use impairment.

Table A5 indicates that, in terms of water clarity, Secchi depths currently used as guidelines equate with risk levels much greater than 10%. Therefore, current guideline/water quality goals are likely under-protective of the uses. In countries and regions where water clarity is an actual regulation for swimming use, the value tends to be >100 cm, or “disk visible on the bottom substrate” (Davies-Colley, et al., 1993), which conforms roughly with the 97 cm threshold value for the 10% risk level.

## "Brown" Scores

Similar analyses were conducted for the brown visual score data, concerning perceived impairment versus Secchi depth and non-algal turbidity. Table A6 presents the values for Secchi depth, while Table A7 presents similar data for calculated non-algal turbidity.

**Table A6.** A comparison of use support versus current interpretation of lake water clarity and 1998-2001 *a priori* "brown" data. All values are in units of centimeters, or cm, of Secchi depth. The "risks" are the Secchi depth threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use. These table values should only be applied to lakes with overt inorganic turbidity.

Lake Use and Support Level	Current Method (water clarity) (Secchi Depth in cm)*	Risk Based Criteria 1998-2001 Brown Data	
		<1%	10%
<b>Aesthetic Use Physical Appearance</b>			
Full Support	>100	>103	>94
Partial Support	>100	103-89	94-70
Non-Support	<100	<89	<70
<b>Primary Contact Recreational Use</b>			
Full Support	>70	>103	>83
Partial Support	>70	103-89	83-57
Non-Support	<70	<89	<57
<b>Secondary Contact Recreational Use</b>			
Full Support	no assessment value	>67	>61
Partial Support	no assessment value	67-40	61-36
Non-Support	no assessment value	<40	<36

\* = These Secchi depth values have been used as goals and guidelines for Kansas lakes, based on best professional judgement and the literature. They have not been used to assess lake use impairment.

Table A7. A comparison of use support versus current interpretation of lake water clarity and 1998-2001 *a priori* "brown" data. All values are in units of "per meter," or  $m^{-1}$ , of non-algal turbidity. The "risks" are the turbidity threshold values at which <1%, 10%, etc., of the public would be expected to observe an impact on the use. These table values should only be applied to lakes with overt inorganic turbidity.

Lake Use and Support Level	Current Method (water clarity) (non-algal turbidity, $m^{-1}$ )*	Risk Based Criteria 1998-2001 Brown Data	
		<1%	10%
Aesthetic Use Physical Appearance			
Full Support	<0.40	<0.53	<0.71
Partial Support	0.40-0.70	0.53	0.71-1.02
Non-Support	>0.70	>0.53	>1.02
Primary Contact Recreational Use			
Full Support	<0.70	<0.53	<0.79
Partial Support	0.70-1.00	0.53-0.95	0.79-1.57
Non-Support	>1.00	>0.95	>1.57
Secondary Contact Recreational Use			
Full Support	no assessment value	<0.68	<1.15
Partial Support	no assessment value	0.68-1.48	1.15-2.62
Non-Support	no assessment value	>1.48	>2.62

\* = These non-algal turbidity values have been used as goals and guidelines for Kansas lakes, based on best professional judgement and the literature. They have not been used to previously assess lake use impairment.

For both sets of data, Tables A6 and A7, the "guideline" values used in the past appear to provide reasonably good threshold criteria for water clarity and turbidity versus recreational and aesthetic use support. These data support the continued use of "best professional judgement" threshold values, for lakes with observable inorganic turbidity.

